LESSON FTR - 30

CATHODE RAY TUBES

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LESSON FTR-30

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All business as now conducted -- particularly those lines of business which embrace the so-called industries -- requires specialized training, in fact so much scientific knowledge that the distinctive line between "business" and "profession" is fast disappearing.

Anyone who hopes to achieve success, even the average, must know more, or at least as much, about some one thing as any other one and not only know, but know how to do -- and how to utilize his experience and knowledge for the benefit of others.

There is too little idea of personal responsibility, too much of "the world owes me a living", forgetting that if the world does owe you a living, you yourself must be your own collector.

-- Theodore N. Vail

Contrary to ordinary belief, the cathode ray tube is not new but has been employed in laboratories for a number of years. However, at present, it has been removed from the laboratory and is now considered as almost a necessity in the Radio industry.

For this reason, a complete understanding of its operation is necessary to anyone interested in electronics and therefore, we are going to spend this Lesson explaining its action and some of its applications.

THE CATHODE RAY TUBE

The cathode-ray tube is a type vacuum tube in which the electrons are concentrated into a beam that strikes the specially treated face or "Screen" and produces a spot of light. Deflection of the beam, which causes motion of the spot, is controlled by means of an electrostatic or magnetic field. Due to the persistence of vision of the human eye, when the spot is caused to move rapidly over the face of the tube, it appears as a line or trace. The trace presents a pattern or image which can be interpreted in terms of the voltage or current causing the motion of the electron beam.

Like the more common vacuum tubes used as amplifiers, the cathode ray tube contains a cathode, a grid to control the electrons, and a plate to attract them. Instead of the usual amplifying action, these elements serve to produce an electron beam whose diameter and velocity they control. One commonly used method for producing the beam is shown in Figure 1, where the electrons, that leave the cathode, are attracted to the anode A1 which is held at a positive potential. To reach the anode, they must pass through the grid which consists of a metal plate with a small hole in it.

The aperture in the grid produces a beam, from the cloud of electrons that are emitted from the cathode, as only those passing through the opening reach the anode A1. The grid is maintained at a negative potential; hence, by varying its potential, it can be made to permit more or less electrons to pass. Since the object of this arrangement is to have the electrons strike the face of the tube, and not remain at anode A1, it also has an aperture which further reduces the beam diameter.

In order that the electrons strike the coated face or screen of the tube with sufficient force to produce a spot of light, it is necessary to increase their velocity. This is accomplished by means of anode A2, which is maintained at a positive potential three or four times that of anode A1, and further concentrates the beam so that a small spot is produced on the screen. The screen is made of a coating of willemite, cadmium tungstate, or other fluorescent materials which have the property of giving off light when bombarded by electrons.

The intensity of the spot of light is determined by the number of electrons in the beam and the velocity at which they strike the screen. One method of controlling the number of electrons is by changing the cathode temperature; however, a better method, which is more convenient, more sensitive, and provides longer tube life, is to vary the grid potential.

The size of the spot is determined by the ratio of the voltages on anodes A1 and A2. The voltage on A2 is usually kept constant and that of A1 is adjusted for proper focusing. If the voltage on A1 is too low, an inadequate number of electrons will reach it; hence, the number reaching the screen will be too small and result in a dim spot. If the voltage on A1 is too high, more than the required number of electrons will reach the screen and the spot will become enlarged. A careful adjustment, of the grid and anode A1 voltages, is therefore necessary to produce a spot of the correct size and intensity.

There are other methods of focusing the electron beam and one of them is by means of the magnetic field produced by a coil placed so that the electrons pass through its core, as shown in Figure 2. Although the magnetic field set up by the coil does not influence those electrons traveling parallel to the flux lines, it does exert a force on those electrons which tend to diverge and move across the flux lines. The electrons are thus kept moving in one direction.

A third method of focusing, developed by the Western Electric Company, makes use of an ionized gas and the tube has the general construction shown in Figure 3.

The cathode is made part of the filament and the grid is connected electrically to it. The number of electrons passing through the grid is controlled only by the cathode temperature since the grid is always at a constant potential with respect to the cathode.

The anode A1 attracts the electrons and gives them the velocity necessary to reach the screen but, in passing through the inert gas, the electrons strike molecules of the gas and knock out some electrons which leaves the molecules with an excess positive charge. These positively charged bodies, called ions, are much heavier and move slowly compared to the electrons; hence, they are displaced very little by the impact and tend to remain in the path of the beam. Since they are positively charged, they attract electrons, thereby preventing the electrons from diverging from the path of the beam. In reality then, there exists a beam of both electrons and ions. While the ions are continually neutralizing electrons, an excess of electrons is maintained by the cathode.

Since motion of the electron can be controlled electrostatically and magnetically, motion of the beam, which consists of a stream of electrons, can likewise be controlled. Deflection is produced electrostatically by passing the beam between two charged plates as shown in Figure 4.

By making plate A positive with respect to plate B, the beam of electrons, which are minute negative charges, will be attracted by A and repelled by B. The spot, which normally appears at Po on the front of the screen, will then move to P1. If the polarity of the two plates is reversed, the beam will be attracted by B and repelled by A and the spot will move to point P2.

The distance that the spot moves from its normal position will be proportional to the charge or voltage on the plates. If the voltage on plate A is increased slowly from zero to the value which deflects the spot to P1, the spot will be seen to move gradually from Po to P1; however, if the increase in voltage is rapid enough, the spot will be seen as a straight line extending from Po to P1. This results from the inability of the eye to follow changes beyond a certain rate. As we have told you before, this characteristic of human eyesight is known as persistance of vision and is made use of in motion pictures. In seeing a line, the eye sees at one time every position that the spot occupied during its deflection.

By using two pair of plates, one deflecting the beam vertically and the other horizontally, the resulting pattern can be interpreted in terms of the voltages applied to the pairs of plates. In reality, this arrangement forms an electrical graph, with vertical and horizontal coordinates, and the motion of the spot, when influenced by two pairs of plates, is shown in Figure 5 where we are looking into the tube from the screen.

Assuming that plate V2 is made positive with respect to V1, the spot will move from Po, the normal position, to P1. If plate H2 is then made positive with respect to plate H1, the spot will move to P2. Now if instead of applying the voltages individually, they are both applied at the same time, the spot will move diagonally from Po to P2; since for each short distance it moves up, it will also move a short distance to the right. If the applied voltages are increased from zero to their final value at sufficient speed, a diagonal line extending from Po to P2 would be seen.

Plates H1 and H2 are known as the horizontal deflecting plates or merely "Horizontal Plates" and V1 and V2 are the vertical deflecting plates or "Vertical Plates". These names result from the direction in which they cause the beam to move and not from their position in the tube.

Similar deflection of the beam can also be produced magnetically, as shown in Figure 6. However, this method is not commonly used for measurement work since considerable energy is required to energize the coils; whereas practically no energy is absorbed in electrostatic deflection of Figure 5. Coils L1 and L2 mounted vertically, deflect the beam horizontally and coils L3 and L4 deflect the beam vertically.

PRODUCTION OF PATTERNS

The pattern, produced by the voltages applied to the deflecting plates of the cathode ray tube, can be determined beforehand by graphical construction. For example, assume that two A.C. voltages of the same frequency and zero phase relation are applied to the deflecting plates of the tube, as shown in Figure 7. The voltage Ev is applied to the vertical plates V1 and V2 and the voltage Eh is placed on the horizontal plates H1 and H2.

At zero voltage, the spot is at Po. After a time t1 has elapsed, the voltage between the vertical plates has increased to the value of e_1 and between the horizontal plates to e_2. The spot then has moved to P1 which is located by projecting horizontally from e_1 and vertically from e_2 to locate point "P1". When a time equal to one fourth of the cycle has passed, the voltage between the horizontal plates is e_4 and between the vertical plates is e_3. By projection, the spot is now at P2. As this point is passed, the voltage starts to decrease and the spot moves down the diagonal to P3, which is reached at the negative peaks of the applied voltages, and then moves back to Po as the cycle is completed.

Thus the pattern of two sine voltages, of the same frequency and zero phase relation, is a straight line. The angle of inclination "α", that the line makes with the horizontal, is determined by the ratio of the magnitudes of the two voltages, and when they are equal, the angle is 45°.

LISSAJOUS FIGURES

By similar construction, it can be shown that if the two voltages are sine waves of equal magnitudes and frequency but with a phase difference, the following will be true:

P

1. For a phase angle greater than 0 and less than 90°, the pattern will be an ellipse, with its major axis making an angle of 45° with the horizontal.

2. For a phase angle of 90° the pattern will be a circle.

3. For a phase angle greater than 90° and less than 180°; the pattern will also be an ellipse but its major axis will make an angle of 135° with the horizontal.

4. For a phase angle of 180°, the pattern will be a straight line whose angle "α" is 135°.

5. For angles between 180° and 360° these patterns will be duplicated.

These patterns, known as Lissajous Figures, produced for the various phase relations, are shown in sketches (A) through (E) in Figure 8.

If the two voltages are of the same frequency but of unequal magnitudes and 90° out of phase, instead of a circle, an ellipse will be produced; however, it cannot be confused with the ellipses produced for phase angles of less than 90° because its axes are in the vertical and horizontal plane as shown in Figure 9.

The patterns resulting from two voltages of different frequencies and of different phase relation are shown in the Lissajous Figures (A) through (D) in Figure 10. All these patterns are for a frequency ratio of 3 to 1, the frequency on the horizontal plates being three times that on the vertical plates. Figure (A) is for a 0° phase angle, (B) for a phase angle less than 90°, (C) is for a 90° angle, and (D) is for a phase angle greater than 90° and less than 180°.

Notice that the patterns consist of double traces, which coincide for a phase angle of 0° and become displaced from each other for other angles. Up to 90° one trace appears to lag the other and after 90°, it leads the other.

The Lissajous Figures produced are determined by the ratio of the two frequencies; hence, if one is known, the other can be determined. As shown in Figure 11, the frequency ratio can be found by drawing a vertical line and a horizontal line tangent to the peaks of the waves produced. The frequency ratio is equal to the ratio of the number of peaks touching the vertical line to the number touching the horizontal line, and these patterns are the same regardless of the frequencies involved. For example, the left hand sketch of Figure 11 would be the same if the frequencies were 30 and 10 or 300 and 100 c.p.s.

MEASUREMENTS

From the properties so far discussed, it can be seen that the cathode ray tube may be used for the measurement of voltage, current, and frequency.

As a D.C. voltmeter, the deflection of the spot, from its original position, can be used as a measure of the voltage applied to the plates. A transparent screen, with parallel lines, placed over the face of the tube will afford a means of calibration. The tube is valuable as a voltmeter because of its extremely high internal resistance; therefore, it will not alter the circuit it is making measurements on.

As a voltmeter, the sensitivity of the tube is expressed in volts per inch or per millimeter of deflection. Once the sensitivity is determined, voltages can be determined from the length of the deflection. ④

On A.C. voltage measurement, the cathode ray tube acts as a peak voltmeter because it produces a line whose length represents twice the peak value. Another valuable characteristic of the tube as an A.C. voltmeter is that the deflection is independent of frequency and therefore it can be used for measuring voltages from D.C. to radio frequencies.

To further increase the sensitivity on A.C. measurements, an amplifier can be used in conjunction with the cathode ray tube but, the amplifier frequency response will limit the frequencies which can be measured. The greatest drawback, to the use of the tube as a voltmeter, rises from its change in sensitivity with a change in anode potentials.

To use the tube as an ammeter, current readings are made by measuring the potential drop across a resistor whose value is known.

For frequency measurement, the output of a calibrated A.F. signal generator is applied to one set of plates and the unknown frequency to the other. The ratio is then determined from the patterns as shown earlier in this Lesson.

SWEEP CIRCUITS

When an A.C. voltage is applied to the vertical plates of a cathode ray tube, a vertical trace appears on the face of the tube. As shown in Figure 12-B, the line represents twice the peak voltage and, in a sense, the observer is looking in the direction of motion of the wave and sees an end view.

To obtain a true picture of the wave, such as shown in Figure 12-A, the beam must be moved horizontally at the same time that it is moved vertically. In order to produce this waveform, while moving vertically from A to B, Figure 12-A, the spot must also travel the distance AM horizontally. When the beam has moved vertically through one cycle, it will have moved horizontally a distance equal to AZ, and one cycle of the wave will be traced on the tube face.

Notice here, to produce a trace of one cycle it is necessary that the beam move horizontally from A to Z in exactly the same time required for the voltage on the vertical plates to complete one cycle.

Suppose the speed of the horizontal motion were cut in half and the beam moved only from A to Y in the time required for one cycle of the voltage on the vertical plates. Under these conditions, the complete wave of Figure 12-A, would be compressed into the horizontal distance A-Y and a second complete cycle would appear in the space Y-Z.

The horizontal speed or velocity of the beam thus controls the number of cycles traced on the tube screen, and while a decrease in velocity will increase the number of cycles, an increase of horizontal velocity will reduce the number of cycles traced on the screen.

From a practical standpoint, the trace should appear to be stationary and therefore the horizontal velocity must be maintained in a definite proportion to the frequency of the voltage on the vertical plates.

Since the width of the screen determines the maximum horizontal distance that the beam can move, to produce a continual picture of the wave on the face of the tube, the beam must be returned instantly from the right edge of the screen, back to the left edge or else a double trace will appear.

The deflection of the beam is proportional to the voltage on the plates and in order that it moves horizontally at a constant velocity, the "sweep" voltage, applied to the horizontal plates, must increase directly with time. At the end of the horizontal displacement of the spot, the voltage will be maximum and then must instantly drop to zero in order that the spot be returned to the origin.

To produce this action, the wave form of the sweep voltage would be that shown in Figure 13 which, because of its shape, is called a "saw-tooth" wave. Checking the curve, you will find that the voltage builds up uniformly with time, reaching a peak value E and then drops instantly to zero.

To produce a voltage wave of this shape, it is customary to use what is known as a "relaxation oscillator" which functions on the charging of a condenser through a resistance. The voltage characteristic of a charging condenser is similar in shape to the line OE of Figure 13 but with a certain amount of curvature which predominates as the peak voltage is approached. However, when this peak voltage is reached, it is necessary to return the spot to its original position and therefore, some means of shorting the condenser must be provided.

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A motor driven switch could be used but, as it would be expensive and cumbersome, a better method is to obtain the same action electrically by means of a gas filled vacuum tube shunted across the condenser, as shown in Figure 14. This tube, which contains two plates, has the property of not passing current until a voltage, high enough to cause the gas to break up into negative and positive particles, is placed across the plates. This condition is known as "ionization" and when it occurs, a very low resistance path exists between the two plates, allowing a large current. The current will stop only when the voltage on the plates is reduced to a value, much lower than that required for ionization.

A tube of this type is ideally suited for the automatic shorting switch in the sweep circuit, for while the voltage is building up on the condenser, the tube acts as an infinite resistance but, after the condenser voltage reaches the ionizing potential, it acts as a low resistance or short. As the condenser discharges, the voltage drop across it is reduced and when the de-ionizing potential of the tube is reached, the current stops as abruptly as it started and the condenser again starts to charge.

The time for one cycle, or the frequency of the sweep voltage, will be determined by the difference in the ionizing and de-ionizing potentials, the value of the resistor, "R", and the value of the condenser, C. The sweep voltage will be equal to the difference of the ionizing and de-ionizing voltages. In commercial circuits, the size of the condenser is changed to obtain large changes in frequency, and the voltage, or resistance, is changed for small frequency variations.

The grid controlled gaseous discharge tube has replaced the two element tube for use in sweep circuits, because of the need for synchronization of the sweep frequency with that of the voltage being analyzed. If the frequency of the signal voltage and that of the sweep circuit do not maintain a constant ratio to each other, the image will move back and forth across the screen making the analysis of the waveform difficult.

To provide a stationary pattern, the two frequencies must be kept in step and synchronization is achieved by feeding a portion of the voltage being analyzed into the grid of the discharge tube, and using it to control the ionizing potential of the tube. As a result, the discharge tube will ionize at the same instant on each cycle of the signal voltage, thereby providing the necessary synchronization.

A simplified circuit using a triode of this type is shown in Figure 15 and while the grid controls the ionizing potential, it has no control over the de-ionizing potential. After ionization occurs, the grid loses control and only by dropping the plate voltage can de-ionization be brought about.

The circuit of Figure 15 functions in the same manner as that described in Figure 14 and the resistor R1 is used to limit the discharge current to a safe value after ionization occurs while the variable bias arrangement is for small frequency adjustment.

As mentioned in the earlier part of this Lesson, the sweep voltage should increase uniformly but the complete voltage characteristic of a condenser would cause a saw tooth wave with considerable curvature and a sweep voltage of this shape would produce a distorted picture. However, the voltage characteristic curve of a condenser is almost straight-line near the start and becomes increasingly non-linear as the condenser voltage approaches that of the supply. By limiting the magnitude of the sweep voltage to a value on the lower part of the curve, a waveform closely approaching the ideal is had. However, by operating on the lower part of the curve, a higher supply voltage will be needed for the same ionizing potential.

The curvature in the charging voltage curve of a condenser is caused by the charging current not being constant in value but if the current could be kept constant, the condenser voltage would vary directly with time. By utilizing the fact that, for a wide range of plate voltages, the plate current of a pentode tube is practically independent of the plate voltage, a method of keeping the condenser charging current constant is available and a sweep circuit, employing a pentode as a current limiting device, is shown in Figure 16.

When the supply voltage is applied to this circuit, the charging current of condenser C will be the plate current of the pentode tube which is determined by its grid and screen voltages. With time, the voltage across the condenser will build up and thereby decrease the plate voltage on the pentode: however since the plate current is independent of this change in plate voltage, the current in the circuit remains constant.

When the voltage across the condenser becomes sufficient to ionize the triode, the condenser discharges through the tube until the voltage on the condenser drops to the de-ionizing potential. When this occurs, the condenser discharge through the triode stops, the plate voltage of the pentode rises and the condenser starts to charge again. Although the circuit current remains constant, the current through the gaseous triode, on the condenser discharge, becomes so large that a limiting resistor R1 must still be used.

THE OSCILLOGRAPH

The cathode ray tube, in combination with auxiliary equipment such as amplifiers, positioning controls and sweep voltage generator, when used for measurement work, is known as an oscillograph or oscilloscope. Although we have explained the various actions of each of the separate circuits, it may be rather difficult for you to visualize just how they would be connected together and therefore, in Figure 17, we show a complete circuit diagram of a typical cathode ray oscilloscope.

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The controls, found on most oscilloscopes, are the intensity, focusing, positioning, amplifier gain, synchronizing and sweep frequency. All of these are shown in the circuit of Figure 17 and we are going to point them out to you.

Intensity Control: From our former explanations, you will remember that the bias voltage on the control grid of the cathode ray tube determined the intensity of the electron beam. Thus, in Figure 17, R25 is the intensity control because it provides a means of varying the bias on the control grid.

Focusing Control: In the tube, the focusing element is the anode and changes are accomplished by means of potentiometer, R23, which varies the anode voltage.

Positioning Control: The positioning control consists of a potentiometer which applies a D.C. voltage of the proper polarity and magnitude to the deflecting plates so that the normal position of the electron beam can be adjusted. It thus affords a means of moving the position of the pattern on the screen. There are usually two positioning controls, one, R14, to move the spot up or down, and the other, R16, to move the spot to the right or left.

Amplifier Gain Controls: The amplifier gain controls adjust the voltage input to the amplifiers and so determine the voltage applied to the deflecting plates. In most oscilloscopes, two amplifiers are incorporated, one for the horizontal plates and the other for the vertical plates. In Figure 17, tube T1 with its circuit is the vertical amplifier and potentiometer R is its gain control.

The horizontal amplifier consists of tube T2 and its circuits, the gain control being potentiometer R2. A switch is incorporated at the input of the horizontal amplifier so that the internal sweep or an external voltage may be applied.

Synchronizing Control: To provide a stationary pattern, the sweep voltage must be kept in step with the voltage to be analyzed. To do this, a portion of the voltage being analyzed is fed into the grid circuit of the discharge tube and used to control its ionizing potential. In Figure 17, this is achieved by feeding back from the plate of T1, through R7, C2 and R5 to the grid of the discharge tube T3. As the amount of this voltage can be controlled by R5, it is the synchronizing control.

Sweep Frequency Control: For a large change of sweep frequencies, in commercial oscillographs, different capacities are substituted in the plate circuit of the discharge tube. In Figure 17 this is accomplished by switch "S" and the six different capacities. For a venier, or small frequency changes, the plate voltage on the sweep tube is varied by changing the position of the movable contact of R9, thus increasing or decreasing the resistance, or load, of the plate circuit.

VISUAL ALIGNMENT

Now that the fundamental action of the oscilloscope have been explained, we are ready to take up its application to the visual alignment of tuned circuits. However, before doing this, we want to draw a comparison between the ordinary signal generator, or test oscillator, and a Radio Broadcasting Station.

As we have previously told you, the ordinary signal generator acts as a miniature broadcasting station by generating a signal of exactly the same character. The main difference is that while the radio station usually broadcasts on only one frequency, a signal generator is arranged so that its frequency may be readily adjusted to any point between the limits of its design. Most commercial signal generators are designed to operate at all frequencies between about 130 K.C. and 30 M.C. or higher in order to act as a substitute transmitter for every broadcast station on the air in addition to generating signals in the intermediate frequency band so that it is possible to properly align the I.F. stages of a superheterodyne receiver.

When the signal generator controls are adjusted so that it is emitting an unmodulated R.F. wave, it is acting exactly like a broadcasting station which is "on the air" but is not transmitting speech or music. In other words, the signal generator's output resembles the radio station "carrier".

When the station transmits sound, the voice or music frequencies are superimposed upon the R.F. signal by feeding the amplified audio signal across a resistor or impedance in the plate circuit of the last R.F. stage of the transmitter. The audio signal voltage alternately bucks and aids the steady plate supply voltage, of the transmitter's R.F. stage and, as a result, varies the amplitude of the R.F. signal.

This produces what is called "Amplitude Modulation" of the R.F. carrier and the amplitude of the resulting signal varies according to the strength of the impressed audio signals. Besides the carrier, additional frequencies are also transmitted, and these are the sum and difference of the carrier frequency and the particular audio frequency which is being transmitted.

In order that you may see this more clearly, let us assume a station which operates on a carrier frequency of 1000 K.C. and is using a pure 1000 cycle audio note for modulation. We now have two frequencies which "heterodyne" or beat together and result in four frequencies instead of the original two. (1) The 1000 cycle audio note, (2) The 1000 K.C. R.F. carrier, (3) The sum of the two signals or 1001 K.C. and (4) The difference between the two signals or 999 K.C.

These last two are called "side band" frequencies and must be accepted by the radio receiver in the same way, and with the same relative R.F. amplitude, as the carrier frequency. Should a 5000 cycle note be used for modulation, the side band signals will be separated from the carrier by 5 K.C. and should also be accepted by the receiver with the same R.F. amplitude as the carrier.

If the original 1000 cycle note was emitted with only half the relative audio volume of the 5000 cycle note, it should be received and emitted from the speaker with the same "volume ratio". If the receiver's R.F. and A.F. stages, as well as the speakers characteristics accept all signals in their correct proportion, the received signal will be a perfect reproduction of the original transmission. However, due to imperfections in transmission, receiver and cabinet design, such flawless reproduction has not been obtained as yet.

One of the difficulties is due to the limited channel widths which are now assigned radio stations. In the regular broadcast band, each station is separated from each adjoining station by 10 K.C. and, as a result, can modulate its carrier only so that the maximum side band frequencies are separated from the carrier by 5 K.C. With a broadcast station operating on a carrier frequency of 1000 K.C., any side band more than 1005 K.C. would cause interference with the station on 1010 K.C. whose lower side band limit is 1005 K.C. and any side band less than 995 K.C. would cause interference with the station on 990 K.C. whose upper side band limit is 995 K.C.

As a result, any fundamental frequency, or harmonic, above 5000 cycles must be sacrificed, but those under 5000 cycles are usually emitted from the transmitter with what is expressed as "approximate flat line frequency response". In other words, all frequencies of the same original amplitude are broadcast without appreciable frequency discrimination.

Let us assume that signals are being transmitted with no appreciable frequency discrimination and see what happens to them between the antenna-ground circuit and the second detector of a superheterodyne receiver.

These signals must pass through a series of tuned stages and, as you know, any combination of inductance, capacity and resistance, such as is found in these tuned circuits, accepts one frequency best and, in varying degree, discriminates against all other frequencies. The actual frequency discrimination ratio will be dependent upon the inherent resistance of the tuned circuit. In general, a circuit with very little resistance has a comparatively narrow acceptance curve while one with considerable resistance has a broad resonance curve. Of course, the more tuned stages, resonant to the same mean frequency, the narrower the resulting band width. ?

From the above explanation you can see that the ideal response, or acceptance, curve of the ordinary receiver should have a flat top, 10 K.C. wide, and straight sides. However, as this ideal curve cannot be had in practice, the alignment of the tuned circuits should be such that it is approached as closely as possible.

AMPLITUDE ALIGNMENT WITH THE OSCILLOGRAPH

Earlier in this Lesson, we told you that the oscilloscope could be used as a peak voltmeter and therefore, it can be substituted for the ordinary output meter in the alignment procedure outlined in an earlier Lesson. A block diagram of such a setup is shown in Figure 18 and if we assume that we are to align a superheterodyne receiver, the signal generator will be set to the I.F. frequency and connected, through a .01 Mfd. condenser to the grid of the last I.F. stage. The horizontal amplifier and sweep oscillator of the oscilloscope will be turned off while the vertical amplifier will be full on and the vertical plates connected across the output of the second detector.

With these adjustments and connections properly made, the units are turned "On" and, after allowing time for the tubes to heat, the intensity control of the oscilloscope should be turned up until a vertical trace appears on the screen of the cathode ray tube. The focusing and positioning controls will now be adjusted for a sharply defined trace in the middle of the screen and if the length of the trace is greater than the diameter of the screen, the output from the signal generator will be decreased.

We are now ready to start aligning the receiver and the primary and secondary trimmers of the I.F. transformer will be adjusted for the maximum length of the trace on the screen. When this stage has been peaked, the output of the signal generator will be connected to the preceding stage and its circuits aligned in the same way.

In other words, exactly the same procedure is followed here as was explained for the alignment with an output meter, the only difference being the type of output indicator employed.

As the modulation frequency of most signal generators is 400 cycles, the above method of alignment shows us the condition at this frequency only but does not tell us what happens when a 2000, 3000, 4000 or 5000 cycle note is transmitted from the radio broadcast station.

In other words, by the above "amplitude modulation" alignment method, it is possible to align all stages of a receiver so that they track correctly, but there are no means of ascertaining the band width. That is, what will happen to the frequencies on each side of the mean or channel frequency. 8

In order to obtain this information, it is necessary to employ what is known as "Frequency Modulation" in which the amplitude of the carrier is constant but its frequency is varied. You will notice that this action is opposite to that of amplitude modulation, in which the carrier frequency is constant but the amplitude varies.

MANUAL FREQUENCY MODULATION

In order to give you a better understanding of this action, let us assume a superheterodyne receiver, aligned for maximum tracking at 1000 K.C. With a signal generator tuned to this frequency and connected to the antenna and ground, a properly connected output meter would show maximum deflection.

Suppose we tune the signal generator 2 K.C. higher than 1000 K.C. or to 1002 K.C., and find the output meter indication is appreciably lower. We then tune it another 2 K.C. or to 1004 K.C. and the meter reading becomes still lower, while tuning it another 2 K.C. lowers the output reading to an almost zero value. We then repeat the same steps on the other side of 1000 K.C. at frequencies of 998, 996 and 994 K.C. When making these tests, we note the actual voltage readings at the various points and plot them on cross section paper. Joining the points with a line we have a curve or graph which looks like Figure 19.

By studying this graph, you can see that the overall selectivity curve of the receiver is too narrow. It is cutting the side bands badly because, when we reach 996 and 1004 K.C., the receiver discriminates against these frequencies by a ratio of about 8 to 1 as compared to the carrier frequency of 1000 K.C. This means that side bands, resulting from a 4000 cycle modulation note would be received at the second detector only about 1/8 as strongly as the carrier frequency.

To remedy this condition, we could align the receiver by varying the signal generator output slowly from 995 to 1005 K.C., and making adjustments until the output meter readings were reasonably flat over this range. As you can see, this would require considerable time and the plotting of several graphs until we obtained the best possible curve. When you stop to consider that all of this work must be done at least twice on each receiver band, once near the high and once near the low frequency end, and that there are from 2 to 5 bands on most all-wave receivers, you can see what a job it would be to check and adjust a receiver by the manual method outlined above.

Fortunately, this is not necessary because, by means of frequency modulation, it is possible to obtain a rapid and constant variation in applied frequencies. Also, by means of the oscilloscope, a constant picture of the band pass of the receiver, with any adjustments you might make immediately reflected in a changed pattern, can be produced on the "scope's" screen.

MOTOR DRIVEN FREQUENCY MODULATOR

One of the simplest methods of frequency modulation is shown in Figure 20 and, excluding that part enclosed by broken lines, you will find that the circuit is nothing but a simple tuned grid oscillator, the operation of which was explained in an earlier Lesson. As you may remember, this circuit will oscillate at some definite frequency, which is determined by the values of L and C. If either L or C is varied, the frequency will also vary.

Keeping this action in mind, a variable capacity, C1, connected across the main tuning condenser C, is rotated by a small motor. Like the common types of tuning condensers, the capacity of C1 will vary from minimum to maximum during one half turn of its shaft and from maximum to minimum capacity during the following half turn. Each complete revolution thus completes a cycle, and the capacity passes through its maximum and minimum values.

Connected in parallel to the main tuning condenser, C, of Figure 20, changes of capacity in C1 cause changes of total capacity and thus, as explained above, cause the frequency of the oscillator to vary. Driven mechanically by the motor, C1 will have a continuous change of capacity and thus cause a continuous variation of oscillator frequency.

With suitable calibration, it is possible to adjust the oscillator condenser to generate a fixed frequency of say 1000 K.C. and, as a result of the capacity change in the frequency modulator condenser, to cause a continuous variation in frequency from 985 to 1015 K.C. thus providing a band width of 30 K.C. or a 15 kilocycle variation each side of the mean frequency. This mean frequency, which is also the resonant frequency of the circuit under test, is often called the periodic frequency.

It is also possible to arrange the frequency modulator condenser with several sections so that two ranges of capacity are available, thereby providing two band widths for any one periodic frequency. The connection between the frequency modulator condenser and the tuning condenser within the oscillator may be made in any manner which is convenient and which will remain constant.

Going back to Figure 20, we will assume that during the first half of the rotation of C1, its capacity decreases from maximum to minimum, causing the frequency to increase from minimum to maximum. Likewise, during the second half of the rotation, as the capacity of the rotating condenser increases from minimum to maximum, the frequency decreases from maximum to minimum.

Consequently, as the condenser turns through one complete revolution, the frequencies swing twice through the band width, which we assumed as 30 K.C. With a motor speed of 1500 R.P.M., or 25 rotations per second, the 30 K.C. band width will be covered in 1/50 second.

Let us further assume that in place of the generator shown in Figure 18, a frequency modulated oscillator, with a band width of 30 K.C., is connected across the antenna and ground terminals of the receiver and both of them are adjusted to a periodic frequency of 1000 K.C. Also, we will assume the frequency modulation condenser rotates 25 times per seond.

When the controls of the oscilloscope sweep, or timing, circuit are adjusted so that the spot of light traverses the screen in 1/25 sec., the pattern will consist of two resonance curves, the left hand one corresponding to the increase in frequency and the right hand one corresponding to the decrease in frequency.

When the timing frequency is adjusted to 1/50 sec., one curve appears on top of the other, the two coinciding at their midway frequency of 1000 K.C. If the circuit response is the same when the frequency is changing from 1000 to 1015 K.C. as when changing from 1000 to 985 K.C., the two curves will coincide throughout their entire length. However, if the frequency response is different from frequencies above and below 1000 K.C., the curves will appear as a two line image.

In general, whatever the frequency range or band width, or whatever the number of rotations per second of the motor driven condenser, two curves will appear on its screen whenever the oscilloscope's timing frequency is about the same as that of the rotating condenser, and will merge when the timing frequency is exactly twice that of the rotating condenser. Instead of the actual frequencies, the image shows their rate of change but, because the timing circuit is synchronized with their rate of change, the horizontal axis of the curve can be calibrated in K.C. and its band width ascertained.

The circuit of Figure 20 is shown merely for explanatory purposes however, in commercial units using a motor drive, the principles of operation are the same. In some models you will find that, instead of varying the capacity, the inductance is changed at a constant rate while in others, a synchronizing circuit may be built right in the oscillator, and arranged to connect to the horizontal plates of the cathode ray tube, making the use of the oscilloscope sweep circuit unnecessary.

ELECTRIC FREQUENCY MODULATOR

One quite common type of frequency modulator in use today operates electrically and thus does not have any moving parts. The complete circuit diagram of such an arrangement, commonly called an "Electrical Wobbulator", is shown in Figure 21.

Checking through the circuit, the 110 volt supply is connected across the primary of the power transformer as well as the series combination of resistors R, R1 and condenser C. The high voltage secondary is connected to the plates of a cathode type, full wave rectifier T1, the pulsating D.C. output of which is filtered by condensers C1, C2 and C3 together with the chokes Ch1 and Ch2.

The D.C. voltage, across the output of the filter is applied to a tube which, you will notice, is a pentagrid converter such as is commonly used as a combined mixer and oscillator in a superheterodyne receiver.

From the output end of Ch2, there is one circuit through R3 to the oscillator anode and another circuit through "R.F.C." to the plate and screen grid. The plate or "Output" circuit is connected to the "Output" terminals, through the coupling condenser C6 and resistor R4. The "Input" terminals connect to the control grid of the tube through coupling condenser C7 and resistor R6.

From the oscillator grid, there is a circuit through the grid leak R2 and grid condenser, C4, the upper part of L1 and back to the cathode. The cathode circuit is completed to B–, which in this case is ground, through the lower part of L1. As the oscillator plate current passes through the lower part of L1 and because of the transformer action between the two sections, this arrangement provides the feedback necessary to cause oscillation. You will notice that the plate or output circuit is coupled to the oscillator grid only through the electron stream inside the tube and therefore, this arrangement is commonly called an "Electron Coupled Oscillator".

From the explanations of the earlier Lessons, you can see that L1-C5 make up the control circuit and the frequency, at which the oscillator operates, will be the resonant frequency of this circuit. As shown in Figure 21, both L1 and C5 are of fixed values and thus, unless other provisions are made, the oscillator frequency will be constant.

Again going back to the earlier Lessons, we told you that the inductance of a coil can be varied by changing the permeability of its core, and this in turn can be varied by changing the amount of magnetic flux passing through it. This is the principle employed in the circuit of Figure 21 in order to vary the inductance of L1 and thus obtain frequency modulation.

Notice, there is a circuit from the rectifier cathode to ground through coils L, L2 and resistor R5. Since coils L and L2 are wound on the same core as L1, current through them will change the amount of magnetic flux and vary the permeability of the core which, in turn will vary the inductance of coil L1 and cause a change in the oscillator frequency.

The normal permeability of the iron core, on which coils L, L1 and L2 are wound, establishes a fixed inductance for the oscillator winding and the oscillator circuit is tuned in the regular way, except that, since a fixed tuning condenser is used, the periodic frequency is fixed and of a single value.

Operating on a 60 cycle power supply, the output of the full wave rectifier, T1, will have 120 pulsations per second, each of which causes a change of current in coils L and L2. As previously explained, changes of current in this circuit will cause the effective inductance of L1 to vary and produce proportional changes of the oscillator frequency.

Thus, the changes of current in coils L and L2 will produce frequency modulation and instead of operating at a single fixed frequency, the oscillator output will regularly swing through a band of frequencies.

The band width, of a frequency modulator of this type, depends on the variation of the core permeability and we will assume it is such that it covers 30 K.C. while the periodic frequency is 600 K.C.

In order that frequency modulation may be obtained at other frequencies, it is necessary to employ the unmodulated output of an ordinary signal generator and make use of beat notes. To show you how this works out, let us assume that a 1000 K.C. unmodulated signal is applied across the input terminals of Figure 21.

This signal will mix with the frequency modulated signal in the oscillator tube and the resultant beat note, appearing in the plate circuit, will be frequency modulated and have a band width of 30 K.C. As explained in the earlier Lessons, this heterodyne action will produce more than one frequency but, it is general practice to use the "difference" beat which, in this case, would be 1000 K.C. - 600 K.C. or 400 K.C. Thus, to produce an output at any frequency, we can apply an external frequency which is 600 K.C. higher than the desired frequency and, by mixing it with the fixed 600 K.C. oscillator get a "difference" beat of the required frequency with a band width of 30 K.C.

Earlier in this Lesson, we told you that some frequency modulated oscillators or "wobbulators", incorporated their own sweep, or time base, and this is employed in Figure 21, by means of the circuit containing resistors R and R1 and condenser C. The voltage, developed across condenser C, is applied to the horizontal plates of the cathode ray tube in the oscilloscope instead of the output of its internal sweep oscillator. The advantage of this system, is that using the power supply frequency for a time base, the time base frequency and rate of change of the frequency modulator are always automatically synchronized because the frequency of the time base is always just one half that of the frequency modulator.

APPLICATION OF TIME BASE

To make sure that you understand the exact way in which the time base spreads the signal out so that a visual picture of the band acceptance of a tuned circuit can be seen, we are going to spend a little more time on it, and will assume the circuit of Figure 21 is employed.

When a frequency modulated signal of constant amplitude is applied to the input of an I.F. amplifier in a receiver, due to the effect of the tuned circuits, the signal across the second detector is constantly changing in amplitude. Therefore, we have available a signal which is varying in amplitude as well as frequency.

However, according to an output meter, or the vertical trace on a scope, the signal amplitude appears to be constant because the variations are too fast for the meter needle to follow and unless some method is devised to show the variations with respect to time, the oscilloscope merely indicates the peak voltage.

As shown in Figure 22, when nothing but the time base terminals of Figure 21 are connected to the horizontal plates of the oscillograph, a straight horizontal line will result. The action here is that the spot, originally in the center of the screen, will move to one side when the supply potential is "plus" and then move back through the center and all the way to the other side when the supply goes "minus", returning to the center when the supply voltage is zero. With a 60 cycle supply, this happens 60 times a second, so that it takes the spot but one 120th of a second to move from full left to full right.

Now let's see what happens when, at the same time this action is taking place, the output of the second detector is applied to the vertical plates. With the I.F.'s properly peaked and the controls of the oscilloscope correctly adjusted, the pattern shown in Figure 23 would appear on the screen. As you can see, this pattern has the shape of a resonance curve.

To show you just how this curve is traced and, to make our explanations definite, we will assume an I.F. frequency of 456 K.C. and start our explanations at the instant the frequency is passing through 456 K.C. on the upward swing towards 471 K.C. Also we will assume that this is exactly the time that the line supply is passing through zero voltage preparatory to swinging the scope spot toward the right.

As previously stated, the I.F. stages have been peaked so that the 456 K.C. signal has the greatest amplification and, as a result, the spot starts at "A" in Figure 23. As the oscillator frequency increases, the higher values are discriminated against with an ever lowering amplification, until they pass through 460 K.C., (B) on the curve, which shows an almost total rejection of the applied frequency.

This condition prevails while the wobbulator signal increases to 471 K.C. and then starts to reduce in frequency. After it passes through 460 K.C. again, the frequencies are amplified more and more until it reaches 456 K.C., at the further-most right side of the image, when the voltage across the second detector is again maximum, point D. At this point, the time base voltage has also reached maximum and is ready to pull the spot in the reverse horizontal direction.

Therefore, after the wobbulated frequency has passed through 456 K.C. toward 441 K.C., the I.F. acceptance amplification factor decreases until it reaches "C" again where full cut-off prevails until it passes through 441 K.C. and reaches 452 K.C. at "B". Here the frequency acceptance of the I.F. amplifier starts to rise until peak voltage at 456 K.C. is reached again at "A".

This action occurs in the first 1/120th second and in the second 1/120th of a second, the action is repeated, except that it is in the reverse direction. The spot moves from "A" to "E" to "F" to "G", back to "F", to "E" and then to "A" completing the cycle.

As we previously told you, by employing a calibrated transparent screen, supplied by most manufacturers with their instrument, in front of the pattern, it is possible to ascertain the acceptance width of the tuned circuit. Any adjustment made on this circuit will immediately be reflected in the acceptance pattern and therefore, by visual alignment, it is possible to obtain the best acceptance curve without taking a series of output meter readings, at various frequencies and manually drafting graphs.

As you already know, in most cases the phase of a signal voltage is shifted 180° between the input and output circuits of a tube. Due to the internal circuits of some oscilloscopes, an amplifier tube may cause this phase shift and cause the curve of Figure 23 to appear upside-down on the screen.

This makes no ~~difference in ordinary work~~ because this phase shift does not alter the shape of the curve which can be "read" equally well in either position.

VISUAL ALIGNMENT PROCEDURE

Now that we have explained the principles of this method, we will assume that we are to align a small superheterodyne, with an I.F. frequency of 456 K.C., using a signal generator, frequency modulator like Figure 21, and an oscilloscope.

The vertical plates of the oscilloscope will be connected across the output of the second detector of the receiver to prevent distortion, due to the audio amplifier, from appearing in the acceptance curve. Also, the connection must be made in such a manner that the phase of the rectified voltage will not be disturbed and thereby distort the selectivity curve. ⑩

After this connection is made, the various units are turned "on" and the spot of the scope adjusted until it is sharp and just visible. The signal generator is then connected as previously explained and the complete receiver is aligned by the amplitude modulation method. While making these adjustments, the vertical amplifier control of the scope is kept all the way "on" and if the vertical line goes off the screen, the output of signal generator is reduced. By following this plan, the A.V.C. system will not be upset.

After the receiver has been aligned by the above method, the internal sweep of the scope is turned "off" and the time base of the frequency modulator is connected to the horizontal plates. The calibrated screen, supplied with the scope is placed in front of the cathode ray tube's face and the horizontal gain control adjusted until the line extends to the outer vertical lines on the screen. Then, the intensity and focus controls are readjusted until the line is thin and sharply defined.

After making sure that its modulation is turned off, the signal generator output is connected to the input terminals of the wobbulator, the output of which is connected across the input grid circuit of the mixer tube through a capacity of about .01 Mfd.

As the I.F. frequency is 456 K.C., the signal generator is tuned to 456 + 600 or 1056 K.C. and, as it approaches the proper frequency, a distorted pattern will be observed on the screen of the scope. When the correct frequency is reached, there will be two images, which overlap in spots, unless the alignment happens to be perfect, and the pattern will look like Figure 24. The I.F. trimmers are then readjusted until the two curves exactly coincide, and the pattern is like Figure 23.

By the use of the calibrated screen, the band pass of the I.F. stages can now be determined and it is generally satisfactory to measure this band width half way up on the curve. Should it be too narrow or too broad, then a readjustment of the I.F.'s will have to be made. However, in most cases, the exact band width will have to be a compromise between selectivity and sensitivity.

When the I.F. stages have been adjusted, the next step is to align the R.F., detector and oscillator circuits. The tuning dial of the receiver is set to 1400 K.C. and that of the signal generator to 2000 K.C. after its output is connected to the antenna and ground terminals of the receiver through a capacity of .0025 Mfd. The oscillator, first detector and R.F. trimmers are then adjusted until a pattern, like Figure 23, and with the desired band pass, is obtained.

The receiver dial is then set to 600 K.C. and the signal generator to 1200 K.C. At this frequency two curves will no doubt appear and the oscillator padder and condenser gang should be adjusted until a single curve with maximum amplitude is obtained.

This completes the alignment for a broadcast receiver but, if several bands are employed, the above procedure should be followed for each.

P

Some receivers will come into alignment perfectly throughout the entire length of the curve, while others because of peculiarities inherent in the receiver design, will have to be completed without perfect symmetry in the selectivity pattern. However, before condemning the design of a receiver, be sure that all of the component parts are in good condition.

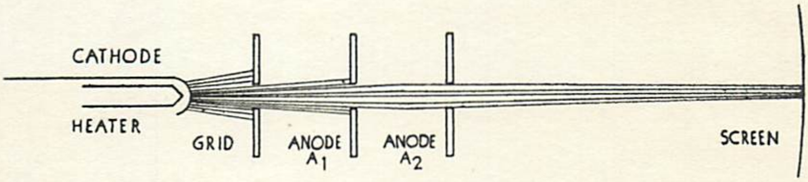


FIGURE 1

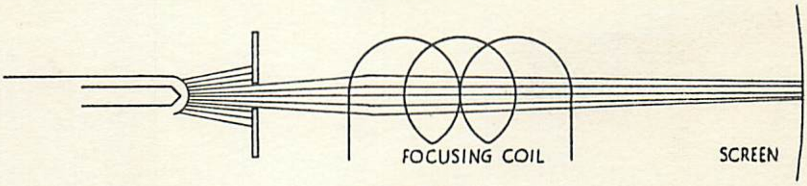


FIGURE 2

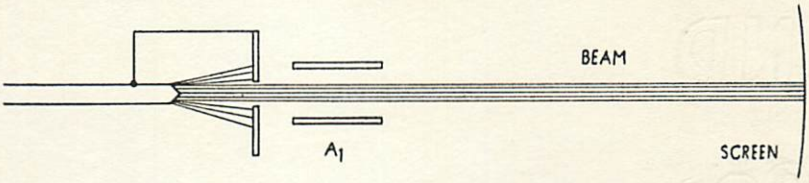


FIGURE 3

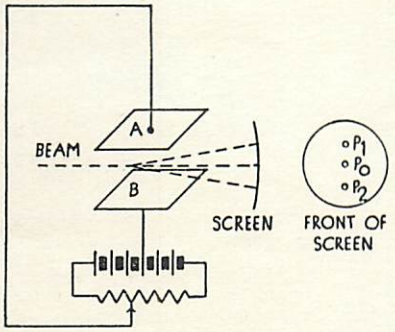


FIGURE 4

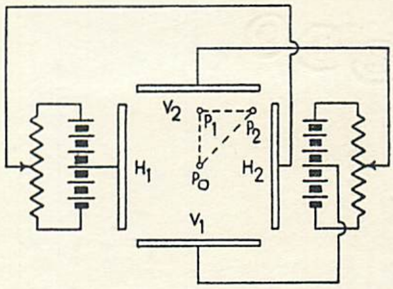


FIGURE 5

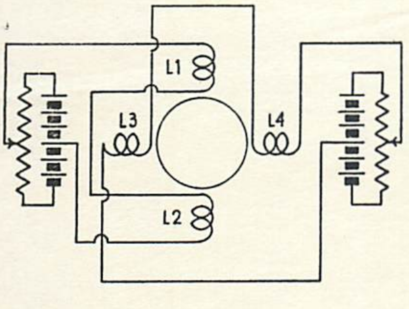


FIGURE 6

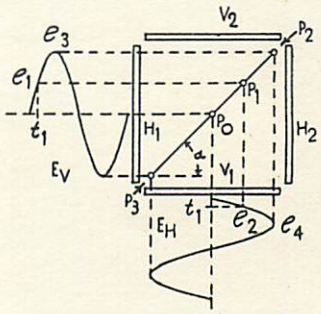


FIGURE 7

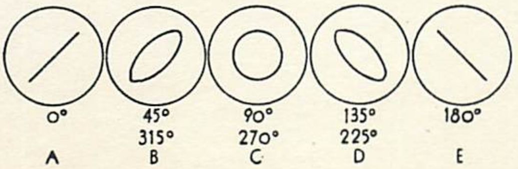


FIGURE 8

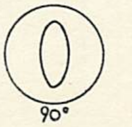


FIGURE 9

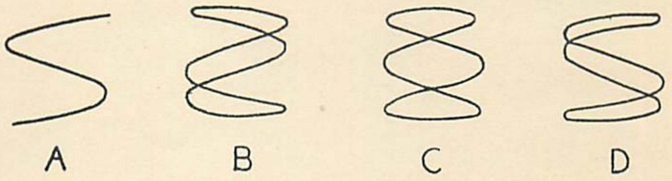


FIGURE 10

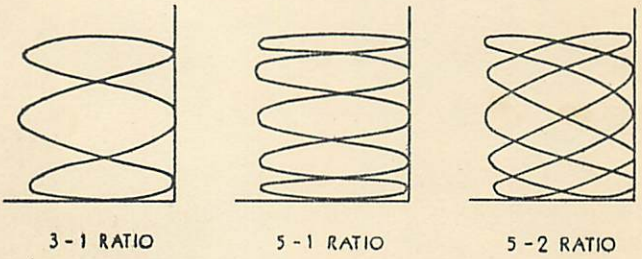


FIGURE 11

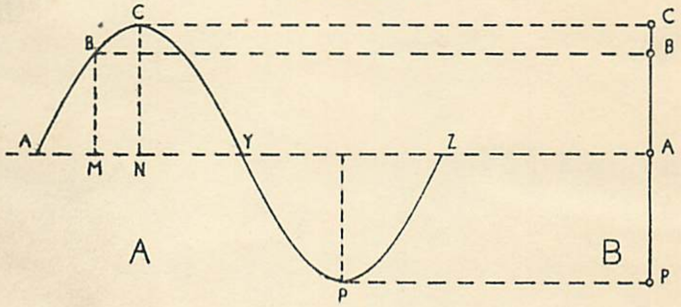


FIGURE 12

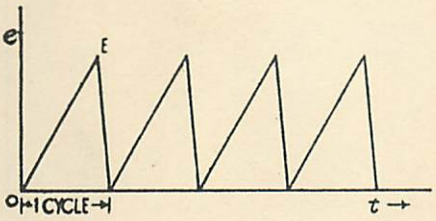


FIGURE 13

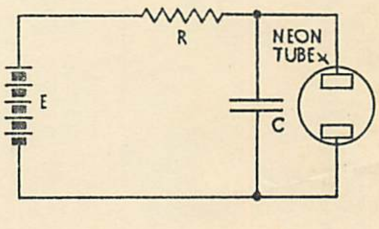


FIGURE 14

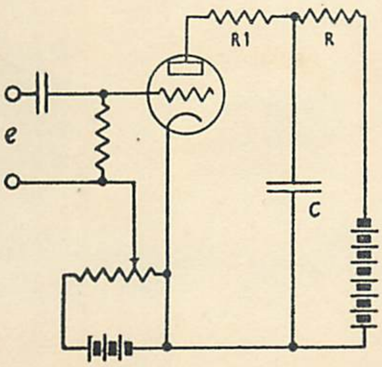


FIGURE 15

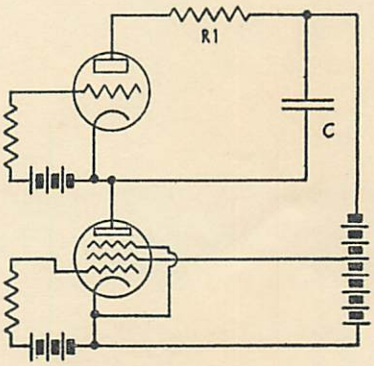
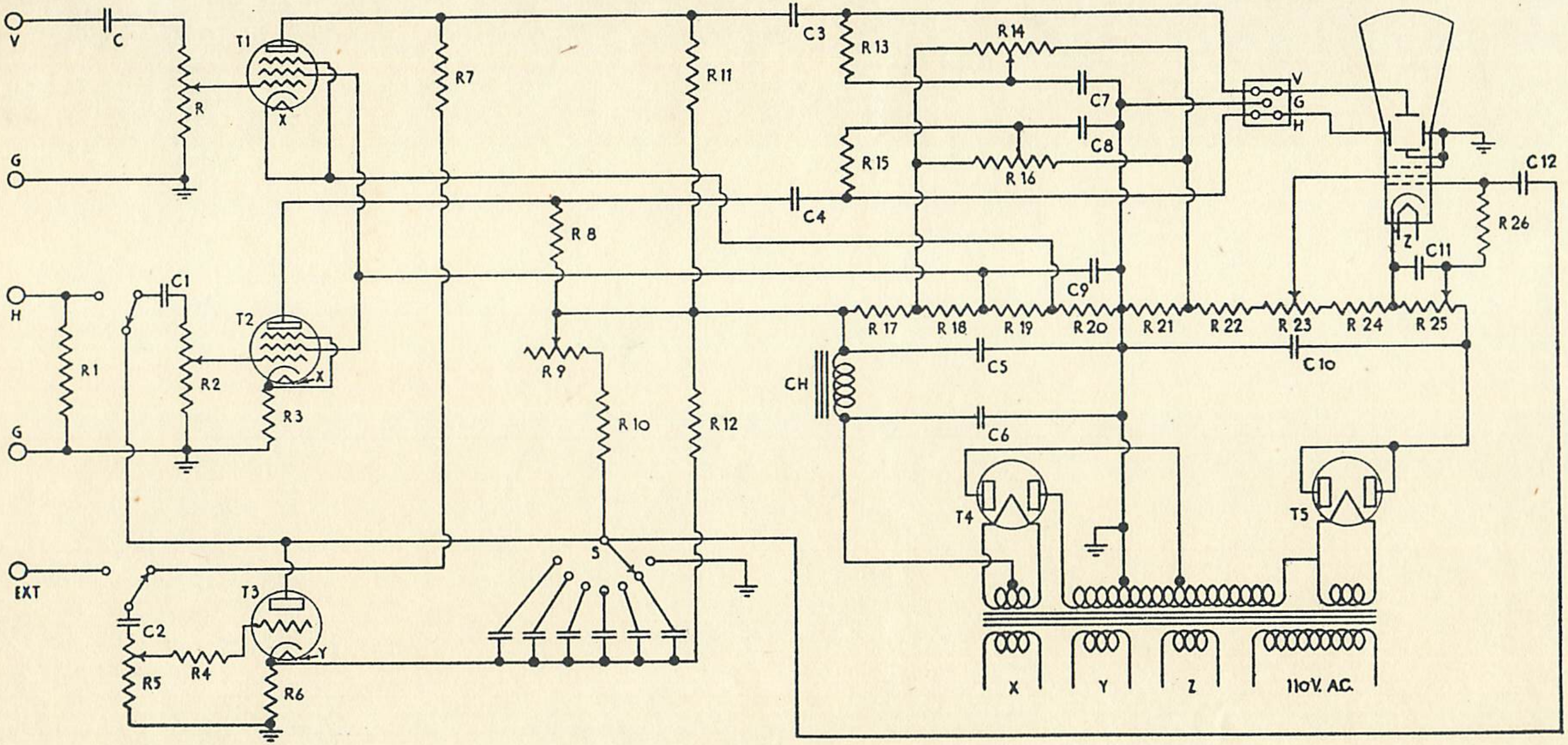


FIGURE 16


V
C
R
G
T1
X
R7
R11
C3
R13
R14
C7
C8
R15
R16
C4
V
G
H
C12
R26
Z
C11
R8
C9
H
C1
T2
R1
R2
X
R3
G
R9
R10
R12
R17
R18
R19
R20
R21
R22
R23
R24
R25
CH
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C10
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110V. AC.

FIGURE 17

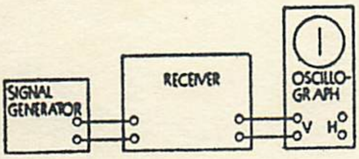

FIGURE 18

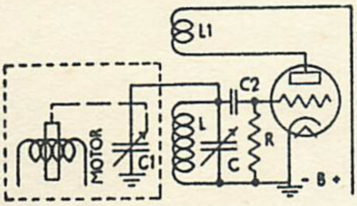

FIGURE 20

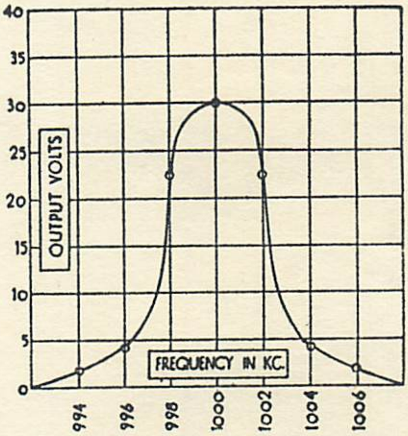

FIGURE 19

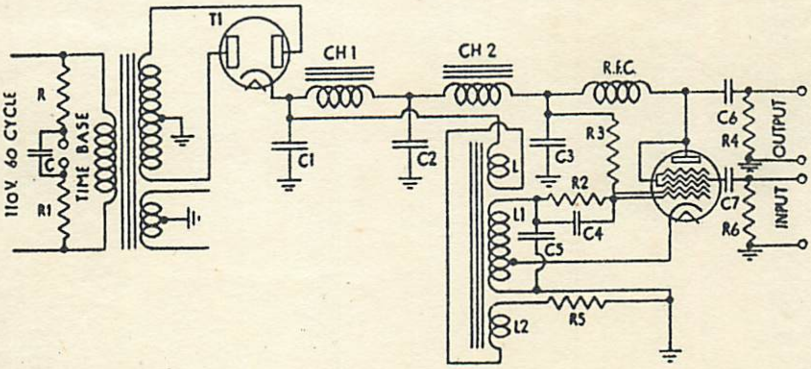

FIGURE 21

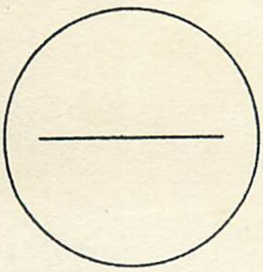

FIGURE 22

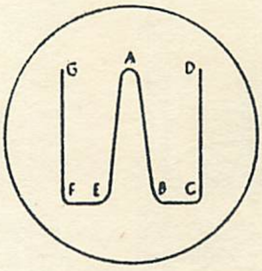

FIGURE 23

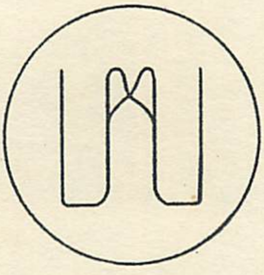

FIGURE 24

QUESTIONS AND ANSWERS

1. What two methods can be used to deflect the beam in a cathode ray tube?
An electrostatic or magnetic field can be used to deflect the beam in a cathode ray tube.

2. What is the purpose of the elements, as a whole, in a cathode ray tube?
The purpose of the elements in a cathode ray tube is to produce an electron beam whose diameter and velocity they control.

3. What determines the distance the spot is moved, from its normal position, in the arrangement of Figure 4?
The distance the spot moves, from its normal position, is proportional to the charge or voltage on the plates.

4. How is the sensitivity of a cathode ray expressed when it is used as a voltmeter?
The sensitivity of a cathode ray tube, when used as a voltmeter is expressed in volts per inch or per millimeter.

5. What type of oscillator is generally used to produce a "sawtooth" wave?
A "relaxation oscillator" is generally used to produce a "sawtooth" wave.

6. What is an "Oscilloscope"?
A cathode ray tube, in combination with auxiliary equipment such as amplifiers, positioning controls and sweep voltage generator, when used for measurement work, is known as an oscilloscope.

7. Upon what does the actual frequency discrimination ratio in a receiver depend?
The actual frequency discrimination ratio in a receiver depends upon the inherent resistance of the tuned circuits.

8. What is the disadvantage of the "Amplitude Method" of alignment of tuned circuits?
The disadvantage of the "Amplitude Method" of alignment is that it shows the relative acceptance of the tuned circuit at only one audio frequency.

9. In Figure 21, how is the inductance of the oscillator coil varied?
The inductance of the oscillator coil of Figure 21 is varied by changing the permeability of its core.

10. Why should the vertical plates of a 'scope be connected across the output of the second detector when visually aligning a superheterodyne receiver?
The vertical plates of the 'scope should be connected across the output of the second detector to prevent distortion, in the audio amplifier, from appearing in the acceptance curve.